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**Risø National Laboratory, Roskilde**

*Publication date:*
1979

*Document Version*
Publisher's PDF, also known as Version of record

# Risø National Laboratory

Risø - M - 2187

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| Title and author(s) | Date |
|---|---|
| Engineering Department - Annual Progress Report for the period 1 January - 31 December 1978. <br><br> Konstruktionsafdelingens årsrapport 1 januar - 31 december 1978. | Department or group <br><br> Engineering <br><br> Group's own registration number(s) |
| pages + tables + illustrations | |

Abstract


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RISØ-M-2187

# ENGINEERING DEPARTMENT

Annual Progress Report

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INIS-descriptors: ENGINEERING, RESEARCH PROGRAMS, RISOE NATIONAL LABORATORY.

UDC 061.62 : 621.039 (489) Risø National Laboratory UDC 62

July 1979
Risø National Laboratory, DK-4000 Roskilde, Denmark

ISBN 87-550-0613-2
ISSN 0418-6435
Risø Repro 1979

CONTENTS

# 1. MAIN ACTIVITY AREAS

This report is intended to give a representative survey of the activities of the Engineering Department during 1978. A short introduction to the main activity areas of the department is provided, followed by brief presentations of selected activities.

Main activity areas are:

- Structural Mechanics
- Engineering Services
- Technical support service and logistics

Work within these areas is performed as part of the overall Risø National Laboratory work programme and also as services for commercial companies and other institutions.

## Structural Mechanics

The general objectives of this field are:

- Basic theoretical investigations within the field of structural mechanics and the subsequent development of appropriate calculational methods and procedure.
- Design or proof calculations of specific structures subjected to static or dynamic loading, as well as thermal stress calculations.
- Experimental analysis including strain measurements on full size objects.

Work has been performed on general purpose finite element computer codes, primarily on a new version of SAP-IV and on the implementation and application of the ADINA-code. A method for calculations of a pretwisted thin-walled beam has been developed, and the work on the corresponding computer code has been initiated.

For DONG A/S (Dansk Olie & Naturgas A/S) consulting services have been made as part of feasibility studies on underground storage of gas in salt domes. The activities include non-linear finite-element calculations and theoretical work on the proper modelling of material properties. For DEFU (Danish Electricity Utilities Research & Development Organization), the department participates in the Gedser Wind Turbine Project (cf. section on strain measurements), and furthermore contributes to the design of the prototype wind turbines, primarily by structural calculations of the rotor blades.

The group has prepared and published 21 reports, articles and conference contributions in the period, and the titles of these are given in the list of references at the end of the present progress report.

## Engineering Services

The general objectives in this field are:

- to develope experimental equipment for all research groups at Risø and to provide these groups with consultation, planning, design, fabrication and commissioning services.
- to make these services available to commercial companies and other institutions within the limits of our resources.
- to provide project management for inter-disciplinary research and development projects especially within the energy field.

Within the engineering field a variety of tasks and projects have been undertaken. Examples of the internal services for Risø groups are: installation and commissioning of shielded boxes and glove boxes in the Hot Cell Laboratory; assembly and installation of the cold neutron source extension at the DR 3 research reactor, and installation of power supply and generator system for the 4KA pulse to THE DANTE Tokamak, previously designed and manufactured by the department (plasma physics research facility). Two projects managed by the Engineering Department on behalf of the Ministry of Commerce concerning uranium extraction and heat storage underground respectively, and the participation in the feasibility study for gas storage in salt caverns have required a substantial proportion of the department's project engineering capacity. These three projects are reviewed presented in later sections of this report.

For a commercial company, testing and calibration facilities for radiation monitors have been designed, manufactured and commissioned, scheduled for operation in the beginning of 1979.

For the Physical Institute at the University at Heidelberg, West Germany, a large number of collimator plates have been ground and polished to strict specifications regarding geometry and surface finish.

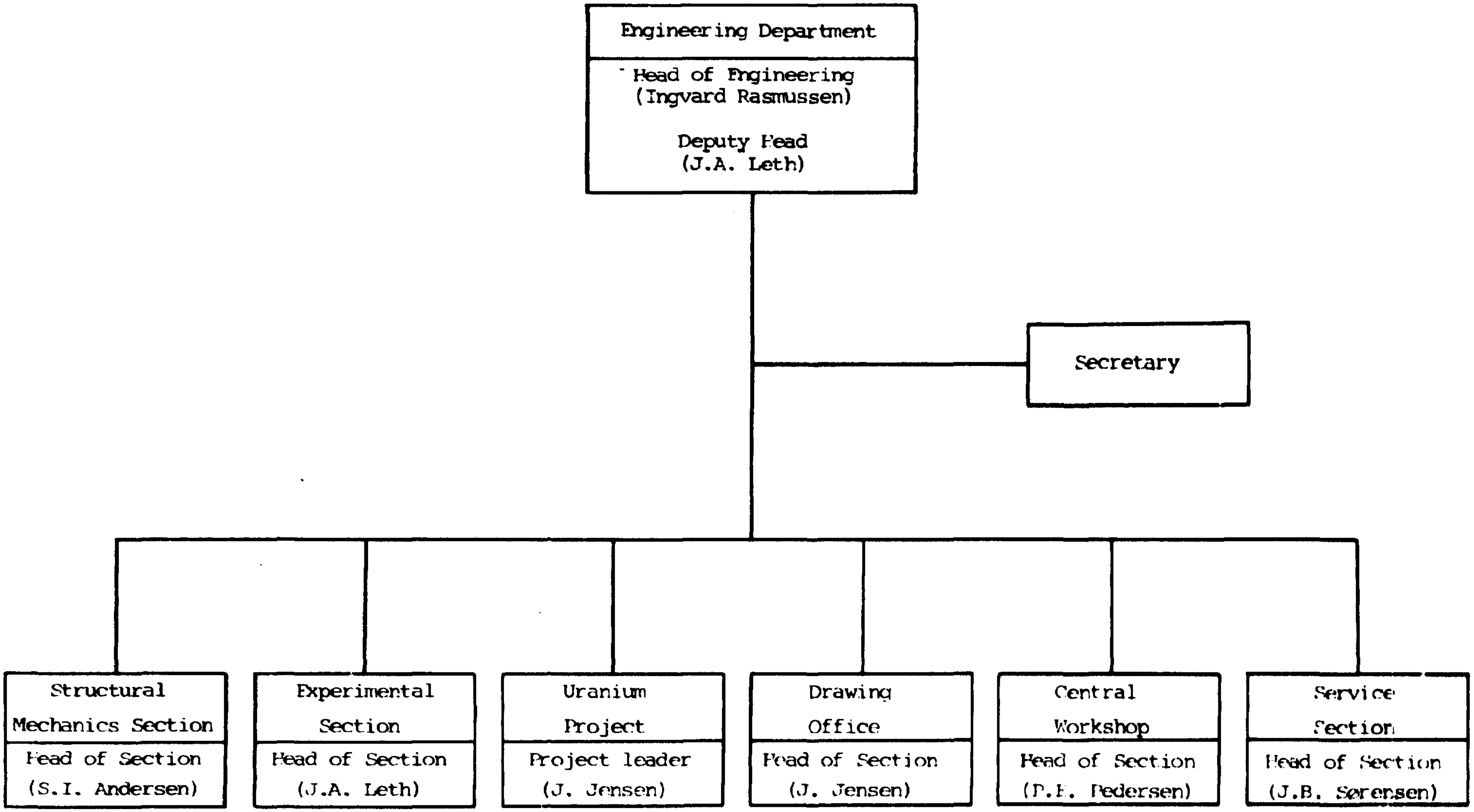
Technical support services and logistics

The general objectives of these activities are:

- maintenance of buildings, technical installations, roads and areas at the Risø National Laboratory.
- operation of central supply services for Risø, including power, water, gas compressed air and heating.
- operation of the Risø internal transportation services.

Specific activities within this field during 1978 were systematic building improvements for energy saving purposes and the planning of an extraordinary general maintenance program to be executed during 1979-80. This program is intended to counteract the effects of the increasing age of the buildings and installations of the center.

By the end of 1978 the Engineering Department had a staff of 134 members: 20 university graduates and engineers, 108 technical staff (including apprentices), and 6 office staff.




Organisation chart of the department.

## 2. EXPERIMENTAL STRESS ANALYSIS

### Strain measurements

Strain measurements have been performed for several years in connection with the structural mechanics work in the department, and the applications have ranged from model investigations under laboratory conditions to full-scale measurements on industrial structures under workshop and/or field conditions.

During 1978 the department has performed contractual measurements on two pressure vessels under proof testing in manufacturer's workshop (Uddcomb Sweden AB): the Reactor Pressure Vessel for the TVO-2 nuclear power plant, and a chemical process vessel (a socalled TRI/PER reactor). Both measurement areas were performed successfully with a very high reliability of the applied gauge installation.

The department has, up till now successfully performed strain measurements on 4 nuclear vessels during the proof testing in the workshop.

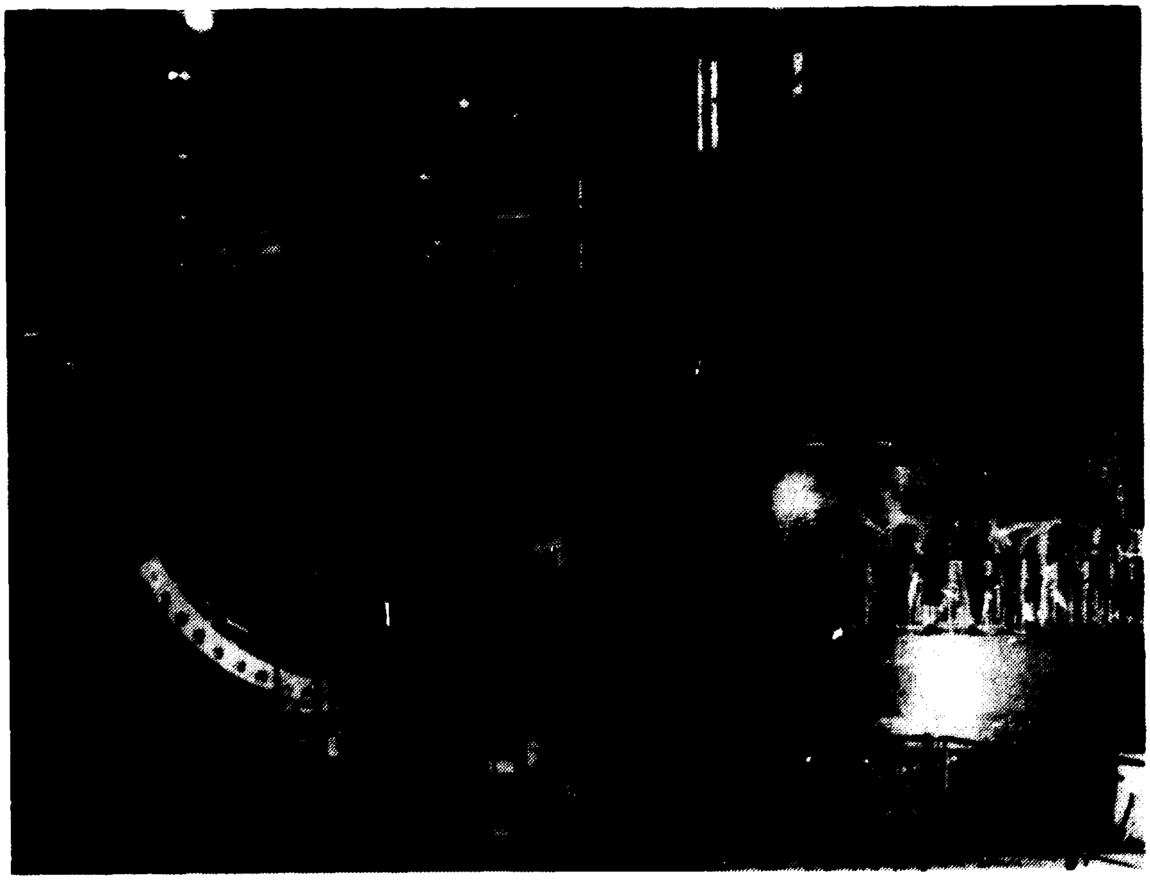


Fig. 1. Nuclear reactor pressure vessel in the manufacturers workshop during the installation of strain gauges.

Fig. 2. Installation of strain gauges in chemical process vessel

An essential feature of strain measurements on pressure vessels is the requirement for reliable strain gauge installations, operating inside the vessel at the test pressure and temperature, typically 100-200 bar and 50°C. The underlying development work has been presented at the 6th International Conference on Experimental Stress Analysis in Munich 1978 (ref. 21).

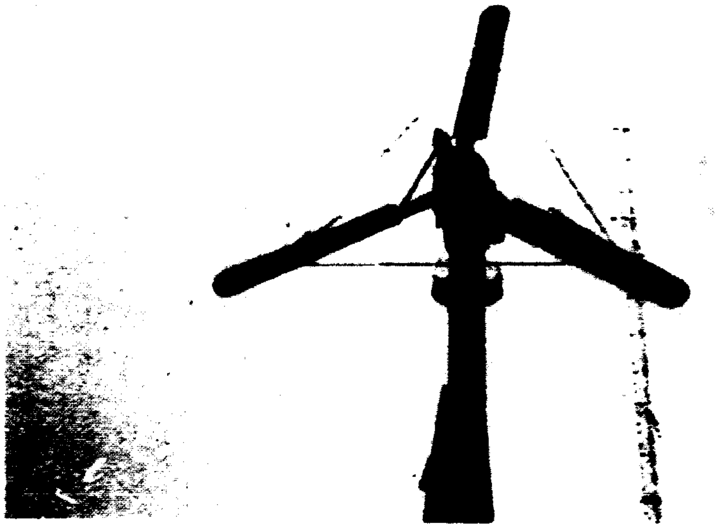


Fig. 3. The Gedser Wind Turbines. Signals from the strain gauges on the rotor blades were transmitted wire-less to the recording system.

As part of the Danish wind power development programme strain measurements on the Gedser wind turbine rotor have been performed in close collaboration with other departments at Risø and with external laboratories (Technical University, Ship Research Laboratory). The strain values were recorded by wireless transmission to a stationary measuring station and recorded simultaneously with the wind and the power characteristics.

Holographic interferometry

Research and development have been performed on measuring techniques, based upon the application of monochromatic, coherent laserlight, for non-destructive testing purposes. The main technique is holographic interferometry, but other types of measurements are performed with the help of laserlight, for instance measurements of surface roughness.

The holographic interferometry technique can be used to measure very small deformations or movements without direct contact with the object during the measurement. One single hologram provides information on the total deformation- or movement pattern of the object. Fig. 4 is an example of this; the deformation of an aluminium-plate, due to bolt tightening, can be seen.

Another important holografic application is vibration analysis. A hologram of a vibrating object at any of its natural frequencies can provide information both on the location of the nodal lines and also the maximum amplitudes.

Fig. 4. Deformation pattern, due to bolt tightening

# 3. NATURAL GAS STORAGE IN SALT CAVERNS

## Introduction

Due to the increasing storage demand for natural gas and oil products a large number of storage facilities, based upon leached caverns in underground salt formations, has been constructed during recent years in North America and Europe. Cavern volumes of 300.000 $m^3$ are not unusual in these plants. The underground storage concept has been preferred rather than surface tank farm storage for reasons of economy, safety and environmental protection.

In connection with the planning preparations for a future Danish natural gas transmission system Risø became involved in feasibility studies on a seasonal peak-shaving storage facility in a salt dome by mid 1977, and the studies were terminated by the end of 1978. The work was performed on a contractual basis for the state-owned company Dansk Olie & Naturgas A/S. Risø assumed the responsibility of a main consultant on the project and entered into close collaboration with the Danish Geological Survey and a series of sub-consultants at home and abroad to ensure access to supplementary know-how.

## Scope of work

The feasibility study included:

- Planning and evaluation of additional field investigations and associated laboratory tests with a view to verify site feasibility in principle.
- A conceptual design study on a complete storage facility.
- Rock-mechanical safety investigations of the cavern concept.

The former activities are reviewed briefly and the latter in more detail in the following.

Field investigations and associated laboratory tests

Based upon geological pre-feasibility studies the location of Ll. Torup in Northern Jutland was selected as the tentative site for a future peak-sha-ing storage facility (figure 5). An exploratory well was drilled during April-May 1978 to a final depth of 1600 m in the salt dome, and oriented drill cores were extracted from different depths for subsequent laboratory testing of the rock salt chemical and mechanical properties. The results from these investigations indicated that the salt dome would be feasible for gas storage applications, but further investigations would be required to provide complete verification.

Conceptual design study

Development of the storage facility will include the establishment of a temporary leaching plant and a permanent gas storage and process plant. The latter will comprise a number of underground cavities, each of 350.000 $m^3$ volume, and the associated surface plant equipment, such as: storage compressor plant, heating, drying and pressure reduction plant, and metering station. The surface plant will be of conventional design, independant of the location characteristica (figure 6).

The conceptual study included technical and economic analysis of a wide range of potential storage development schemes, in which storage capacity and construction time were the main variables. Documentation from major European contractors was applied as background information for the study.

Rock-mechanical safety

As for normal engineering structures, safe design of a cavern facility includes 2 main steps: detailed studies and overall weighing of the results. The main safety aspects related to gas storage caverns are leak-tightness, mechanical strength under extreme loadings (max. and min. operating pressure, occuring once a year), and long-term stability.

Caverns will typically be constructed at 1000-1500 m depths, where leak-tightness will be ensured by the high formation press-

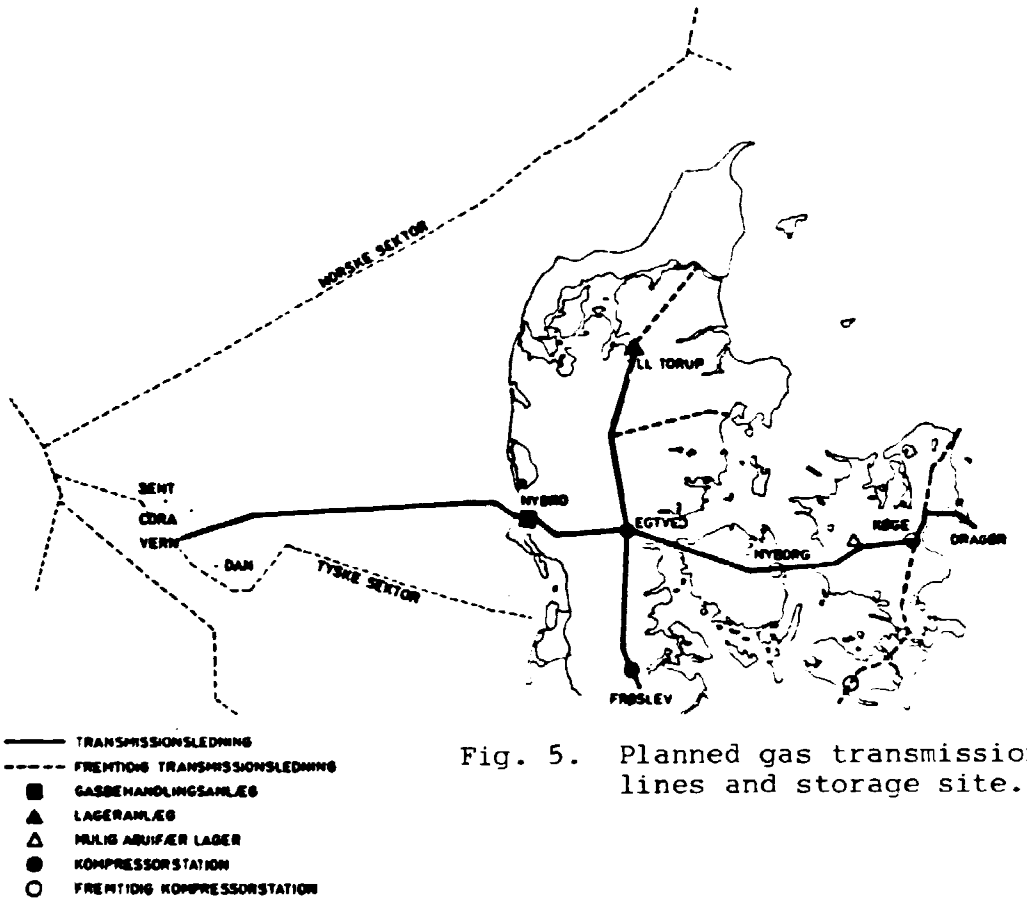



Fig. 5. Planned gas transmission lines and storage site.

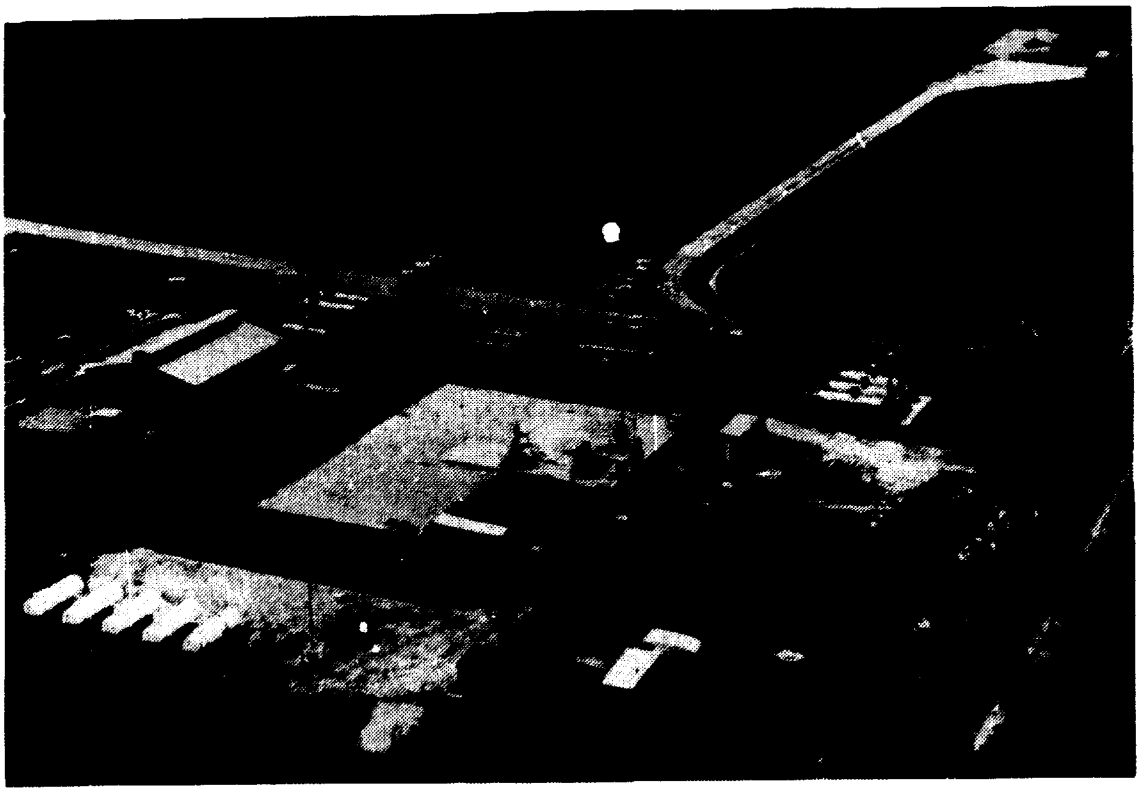


Fig. 6. Natural gas storage plant with underground storage in Northwest Germany. (EWE-photo)

ure (approx. 250 bar) and the plastic properties of the rock salt.

The plastic behaviour should also be taken into account in the analysis of the safety margin against failure in the cavern walls. Two essentially different conditions should be fulfilled: first, the overlying salt strata should not be fractured at max. operating pressure, and secondly, the cavern walls should remain stable at the lowest occurring gas pressure. The former condition is fulfilled by restricting the max. pressure to a level essentially below the total weight of the overlying strata, and by special design precautions for the casing assembly.

Design considerations related to lower gas pressures must include both the annual minimum operating gas pressure and also potential depressurization of the cavern to atmospheric pressure in case of accidents. It is therefore desirable to design the cavern for short-term stability under atmospheric pressure.

Two types of stress analysis methods have been applied for the investigations of the low-pressure situation: an analytical approach based upon simplified assumptions concerning cavity geometry and material behaviour, and a non-linear finite element approach using the AXISYM-computer code (figure 7). The results from the two methods showed good agreement in the critical area at cavern mid-height. Selected results from the finite element analysis are illustrated by figure 8, which shows the extent of plastic areas round the cavern at max. operating, min. operating and atmospheric pressures, respectively.

Long-term cavern stability is related to a progressive volume reduction, which may have a gradually increasing impact upon overall operating economy, and may also lead to potential subsidence at surface level. Only the latter aspect is safety-related.

Future activities

Risø is at present involved in subsequent stages of storage project, including both general engineering activities and also more detailed studies on rock-mechanical safety.

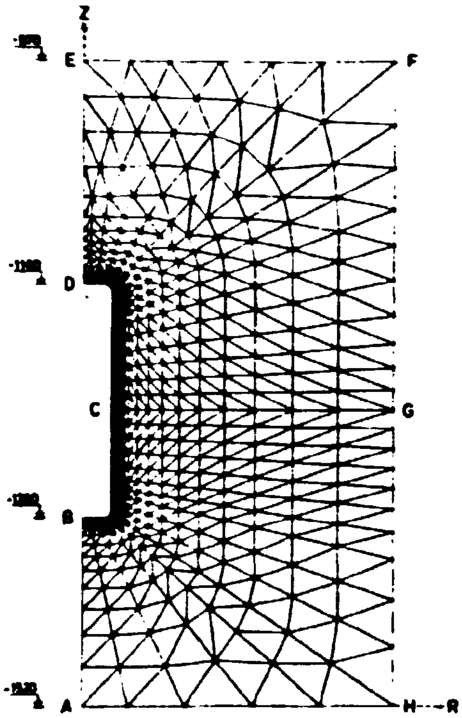



Fig. 7. AXISYM-mesh of idealized cavern geometry

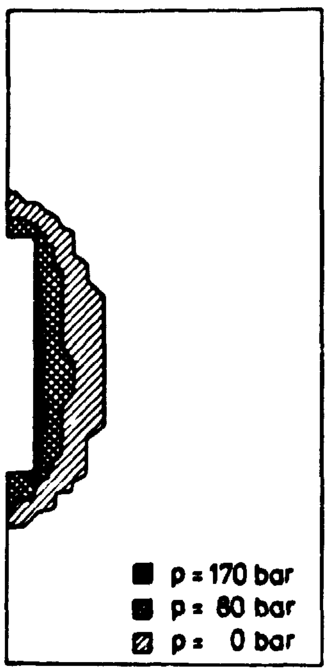



Fig. 8. Areas of non-linear material behaviour round cavern

# 4. UNDERGROUND HEAT STORAGE

## Introduction

A significant part of the demand for both heat and electricity in Denmark is met through combined generation. About 10 percent of the residental heating requirements are presently being supplied from combined generation plants and efforts are made to increase this part significantly in the future.

In systems containing combined heat and power generating units the use of seasonal storage of warm water may lead to sizable savings of fuel, installed power capacity, and money. This is, in particular, due to the climatic conditions, characterized by a fairly long winter heating season and a reasonable warm summer without large cooling requirements, and with the heating requirements of residential areas limiting itself to the supply of hot water.

Seasonal storage of warm water has to be very cheap. The economic balance of seasonal storage shows that only the very cheapest solutions could be considered. Our inclination, therefore, has been to look for the presence of potential natural sites for storage of warm water. Furthermore, these have to be located very near existing or planned district heat pipelines.

The project described below concerns storage of heat underground in layers of sand or gravel.

## Scope

The goals of our heat storage project are:

- to develop mathematical models for simulation of heat transport by means of streaming hot water in porous geological layers.
- to demonstrate the practical and economic aspects of underground heat storage by means of a test plant.

- to make a survey based on available hydrological and geological data in order to find possible sites for underground heat stores near potential areas for district heating supplied from combined electricity and heat generating stations.

Mathematical models

Mathematical models for simulation of heat transport by means of streaming water are important tools for the design of underground heat stores.

The models should be able to make calculations of temperature, pressure and velocity in stores in different geological structures and with different geometrical configurations.

The models will be developed in steps from simple to more complex versions. The first models are used for design of the test plant, whereas the final models will be used in the analysis of the results from the test plant, and for evaluation of future plants.

Test plant

The purpose of building a test plant is to verify the theoretical concept of seasonal, underground heat storage.

The working principles of the test plant are as following:

The heat is stored in the underground by injecting heated subsoil-water in the center (see fig. 10).

The cold subsoil-water is gained from a ring of drillings around the center. When the heat is needed, the flow direction is reversed.

The transfer of heat between the underground heat storage and the heat distribution network is carried out by heat exchangers.

The storage site will be chosen in an area of suitable geological structure and with the possibility of being connected up to a heat distribution network. The first step after the location of this site will be an experimental verification of the geological and hydrological properties of the underground. At the same time the design of the test plant will be started.

The final design will be adapted to the results of the experimental investigation of the hydro-geological properties of the site.

Project management

The project is carried out jointly by three institutes:

- Technical University of Denmark (Laboratory for Energetics).
- Risø National Laboratory.
- Geological Survey of Denmark.

The project is managed by the Risø National Laboratory.

Status for the project

2-dimensional mathematical models are now ready for use. A parameter study of the store by means of the models has been performed. Hydro-geological investigations on a site at Randers has been started.

The project is expected to run to the end of 1982.

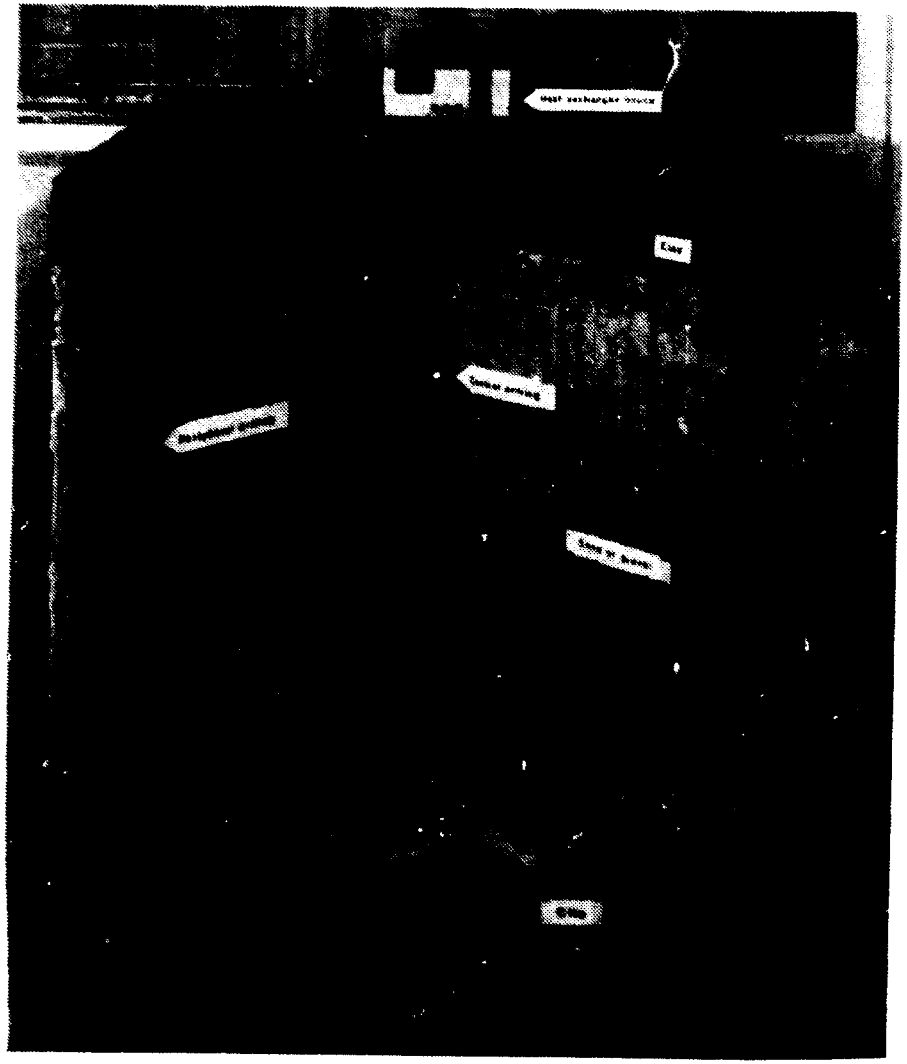


Fig. 10. Model of heat storage test plant

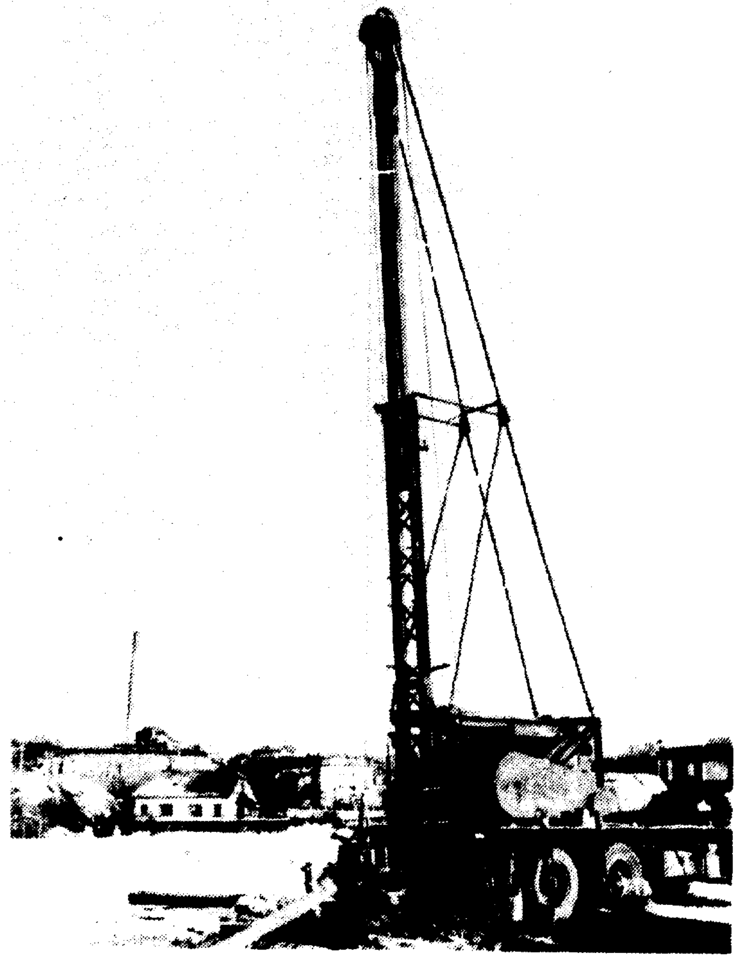


Fig. 11. Drilling rig

## 5. URANIUM EXTRACTION

The only occurrence of uranium ore so far found on Danish territory is the Kvanefjeld deposit in southern Greenland, which has been investigated since 1957.

While most uranium deposits exploited throughout the world are sediments containing secondary uranium minerals with a grade of generally above 800 ppm, the Kvanefjeld ore is of magmatic origin with the uranium bound in refractory phospho-silicates and an overall grade of only 340 ppm.

The host rock is called lujavrite, which is a type of alkali-rich syenite.

In 1977 an extended drill programme revealed a uranium resource about three times the previously known amount.

The tonnage depends on the cut-off grade in the following way:

| Cut-off-level (ppm U) | Uranium (tons) | Average grade (ppm U) |
|---|---|---|
| 50 | 44.000 | 210 |
| 250 | 27.000 | 346 |
| 300 | 21.000 | 375 |
| 350 | 13.000 | 414 |

For the leaching of uranium from its ores the choice of reagents in practice is between sulphuric acid and sodium carbonate. The first is generally more effective and it finds by far the widest application, but with alkaline rocks, which are too acid-consuming, the carbonate leaching must be considered.

The effectiveness in the present case is highly improved at about 250$^{\circ}$C as shown in numerous laboratory experiments. The recovery may vary between 70 percent and 90 percent according to the origin of sample.

For the construction of a plant along these lines a serious obstacle is the pressure of about 60 atm. required to keep the leach liquor in the liquid form at the elevated temperature and for the introduction of the necessary oxygen.

Fortunately a simple method for the continuous leaching of ores under pressure has recently been developed in Germany. It consists of the pumping of a slurry of ground ore in a sodium carbonate solution through a very long pipe in which the heating is ensured. The velocity is so high that a turbulent mixing takes place. Before the outlet the bore is reduced in order to bring the pressure down to atmospheric. Subsequently the slurry is filtered for separation of uranium pregnant liquor from solid waste.

Because the strong carbonate solution is not amenable to ion exchange another method has been tried for the processing of the liquor. It is based on the reduction by hydrogen of the uranyl carbonate, by which the uranium precipitates as the insoluble black oxide $UO_2$. The reaction takes place at 150°C under a 15 atm. hydrogen pressure.

Many of the remaining problems car only be satisfactorily solved in a pilot plant, which is being planned for the purpose. A sample of 5000 tons will be mined during 1980.

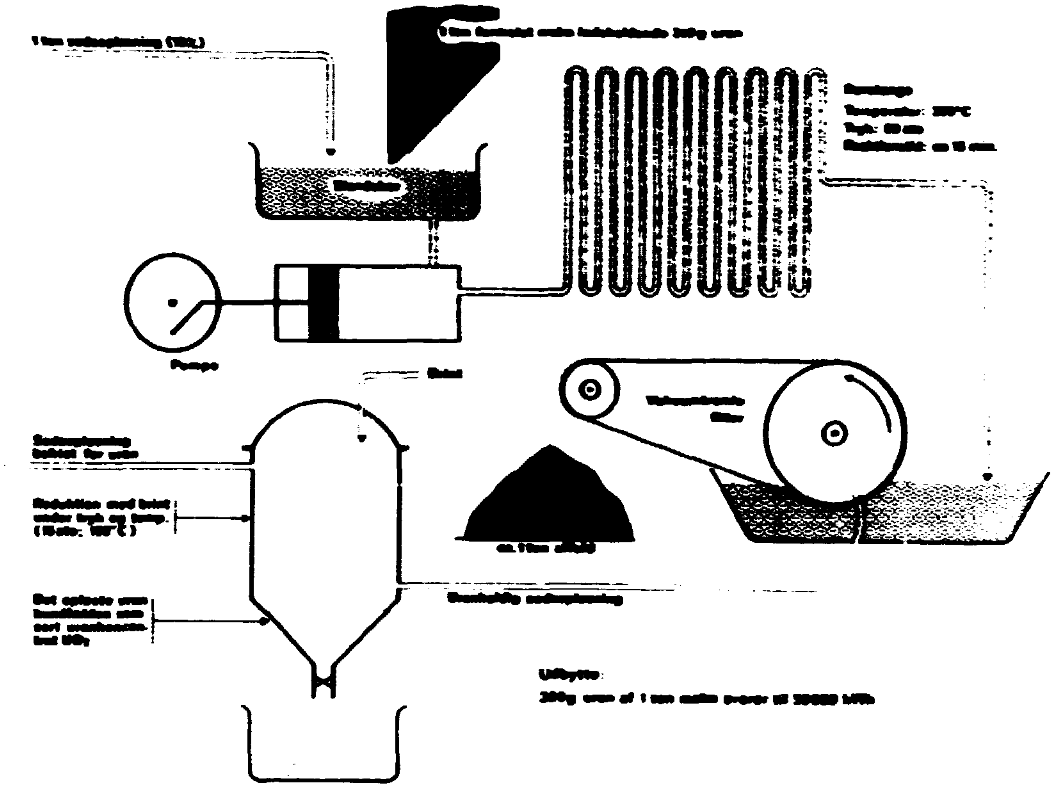


Fig. 12. Process diagram for the conceived pilot plant

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